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EVALUATION OF LIQUID ORGANIC MATERIALS FOR SECURING NUTS ON TRANSMISSION TOWER ANCHOR BOLTS

Report No. 90-109-K

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ABSTRACT

Four organic materials were evaluated for possible use in the assembly of transmission tower anchor bolts. These materials are being considered to secure the anchor bolt nuts, so as to prevent or limit unauthorized persons from removing them. These materials were evaluated by determining the breaking and prevailing torques developed when they were applied to various anchor bolt assemblies. Important test variables were the diameter of anchor bolt used, the ambient temperature during application and curing of the materials, and the amount of pretorque initially applied when tightening each nut.

Based on the results of this program, two materials are recommended for use. An epoxy-based material is recommended for use at an ambient temperature between 30⁰ and 0⁰C, and a modified vinyl ester-based material at subfreezing temperatures. Future studies will include field evaluation, as well as a study into the long-term performance (ie, strength and durability) of these two materials.

job	file	date	report no.
42-117-431 42-305-431	842.44(P)	June 15, 1990	90-109-K

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To Mr. H. Dey
Supervising Design Engineer
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**EVALUATION OF LIQUID ORGANIC MATERIALS FOR
SECURING NUTS ON TRANSMISSION TOWER ANCHOR BOLTS**

1.0 INTRODUCTION

An investigation was conducted to evaluate the suitability of using liquid organic compounds in the assembly of transmission tower anchor bolts. These materials are being considered to secure the anchor bolt nuts, so as to prevent or limit unauthorized persons from removing them. This particular investigation is a more comprehensive study that is a follow-up to the promising results obtained in a preliminary study completed in August-September of last year/1/. The purpose of this report is to present the details, results and conclusions of the current investigation, which was conducted between March and April, 1990.

2.0 DESCRIPTION OF TEST PROGRAM

2.1 General

Four candidate products (Table 1) were evaluated by determining the breaking and prevailing torques developed when these materials were applied to various anchor bolt assemblies (see Figure 1). A total of 48 anchor bolts were tested (after a predetermined duration of curing) by securing each bolt in hydraulically actuated grips (Figure 2a) and removing the nut with a calibrated pneumatic torque-multiplying tool (Figure 2b). Important test variables included the diameter of the anchor bolt, the ambient temperature during application and curing of the materials, and the amount of pretorque initially applied when tightening each nut. Two anchor bolts of each diameter, using each product, and at each condition (ie, ambient temperature and amount of pretorque) were tested. A complete matrix of the anchor bolt tests is given in Table 2. Further description of the materials tested and more details on the test variables and test procedures are given below.

2.2 Materials

A general description of the four materials is as follows: (see also Table 1)

(a) VLT Bolt Adhesive #1 (BA#1)

This material is based on a highly plasticized (10% by mass of sample) modified vinyl ester resin with a filler content consisting of silica flour and calcium carbonate particles. The resin is catalyzed with a 50% active powdered form of benzoyl peroxide (BPO).

The high plasticizer content of the resin will result in a more flexible hardened product, which theoretically will enhance the prevailing torque by clogging in the gap between the threads of the anchor bolt and nut. Further, the calcium carbonate particles are also meant to enhance the prevailing torque resistance, by similarly having these particles crush and jam between the anchor bolt and nut.

(b) VLT Bolt Adhesive #2 (BA#2)

This material is similar to BA#1, except that it contains no plasticizer. Being more rigid, it is therefore expected that the breaking torque developed by this product will be greater than that of BA#1, but with a lower prevailing torque.

(c) VLT Bolt Adhesive #3 (BA#3)

This material is similar to BA#2, except that the filler content has been reduced to improve its workability. (Note: This deficiency in workability of BA#2, particularly at subfreezing temperatures, was actually identified after the program had been initiated. See further discussion in Subsection 3.3.)

(d) Capbond HS - Rapid (Capbond)

This epoxy-based material was identified as the most promising compound in the previous test program/1/. Capbond was included in this present program, to not only confirm the results of the previous study (as recommended by Reference 1), but also to see if its use can be extended to a low ambient working temperature of 0°C.

2.3 Test Variables

The test variables are described as follows:

(a) Anchor Bolt Size

Two different diameters of straight, deformed bar, galvanized anchor bolts were used. These bolts conformed to Ontario Hydro Specification M285-87a and the two diameters were 28.5 mm (1-1/8 in.) and 38 mm (1-1/2 in.).

(b) Placing and Curing Conditions

All materials were tested (ie, applied to the anchor bolt assemblies and cured) at 22°C. VLT Bolt Adhesives #1, #2 and #3 were also tested at -15°C, and Capbond HS - Rapid was additionally tested at 0°C. When applied at 22°C, the materials were allowed to cure, at that temperature, for 7 days. For the -15°C and 0°C temperatures, the materials cured for 6 days at those temperatures, followed by an additional 24 hours at 22°C. The bolts were maintained in a vertical position for the application and curing of the materials.

(c) Amount of Pretorque

The anchor bolts were prepared by either hand-tightening the nut (ie, no pretorque load) or by applying pretorque loads of 270 N.m (200 ft.lb) and 410 N.m (300 ft.lb) to the 28.5-mm (1-1/8 in.) and 38-mm (1-1/2 in.) diameter bolts, respectively. The preloads were applied by using a calibrated, pneumatic torque-multiplying tool to

tighten the fastening nut against a bearing plate, which was in turn supported by a second nut (see Figure 1). The anchor bolts were held in a hydraulically actuated grip during this operation (see Figure 2).

2.4 Anchor Bolt Preparation, and Material Mixing and Placing Instructions

All loose dirt, grit, grease, etc., were removed from the threads and washers of the bolts with the use of methyl ethyl ketone (MEK) solvent and light wire brushing. For 24 hours prior to applying the materials, all anchor bolts and materials were preconditioned to the appropriate application and curing temperatures (see Subsection 2.3), the exception being Capbond at 0°C, where the material was stored and mixed at 22°C before being applied at 0°C.

All materials were proportioned (see Table 1) and mixed according to Manufacturers' instructions. The materials were applied with a 25-mm (1 in.) wide paint brush to both threaded surfaces (ie, around the perimeter of the bolt and on the inside of the nut). Once the nut was threaded into position (and pretorqued, as applicable), additional material was brushed onto the exposed threads above the nut.

2.5 Additional Tests

Concurrent with the anchor bolt tests, additional tests were carried at 22°C, 0°C and -15°C to determine some physical characteristics of the materials.

Gel, tack and hard times were determined for all materials at 22°C. Additionally, these tests were conducted at -15°C for VLT Bolt Adhesives #1, #2 and #3, and at 0°C for Capbond HS - Rapid. Gel times were determined by monitoring the reaction (ie, gelling) of a 100-mL sample of each material at the various test temperatures. This information will be useful in providing guidance on available working times once a material is mixed. The tack and hard times were determined with the use of a Dry Time Recorder. Here the time required for a thin film (0.5 mm) of each material (at the various test temperatures) to become tacky and to harden was determined. The purpose of testing thin films, of each material, was to determine these times relative to a typical thickness that would be applied in an actual anchor bolt installation.

The compressive strength of all materials was determined at 1 day and 7 days for samples of all materials cast and cured at 22°C. Compressive strength tests were also conducted, at similar ages, for samples of VLT Bolt Adhesives #1, #2 and #3 and Capbond HS - Rapid, which were cast and cured at -15°C and 0°C, respectively. Compressive strengths were determined in accordance with ASTM C 109.

3.0 RESULTS, OBSERVATIONS AND DISCUSSION

3.1 General

The results and observations obtained during all phases of testing are reported. It should be noted that, early in the program, VLT Bolt Adhesives #1 and #2 were found to be unacceptable for further testing (as discussed below). While a complete set of gel, tack and hard times had been obtained for these two products, the bolt tests scheduled at -15°C for these products (see Table 2) were not conducted due to problems identified in the

22°C bolt tests (see further discussion in Subsection 3.3). Therefore, the emphasis in further discussion will be on the results and observations for VLT Bolt Adhesive #3 (BA#3) and Capbond HS - Rapid (Capbond).

3.2 Additional Tests

3.2.1 Gel, Tack and Hard Times

The gel, tack and hard times for all materials, at the applicable test temperatures, are reported in Table 3.

At 22°C, BA#3 and Capbond had gel times of 25 and 5 minutes, respectively. This observation was generally confirmed when working with these two materials in the 22°C anchor bolt tests. Practical periods of use, when a large volume (usually in excess of 1000 mL) of these materials was mixed to apply to the various anchor bolt assemblies, were approximately 15 and 8 minutes for BA#3 and Capbond, respectively. At -15°C for BA#3 and 0°C for Capbond, the gel times increased to 230 and 23 minutes, respectively. As inferred from these results, the periods of practical use for these materials (at these lower temperatures) were longer; however, their initial workability was poorer.

The tack and hard times at 22°C for a thin film (0.5 mm) of BA#3 were 12 and 30 minutes, respectively. The corresponding times for Capbond were 80 and 240 minutes, respectively. These results indicate that BA#3 will be generally resistant to environmental effects (eg, rain) within approximately 12 minutes of being applied to an anchor bolt assembly, whereas Capbond will require at least 80 minutes to develop a similar resistance. Therefore, nominal protection of Capbond, such as covering with a plastic sheet, is recommended if inclement weather is forecast within a few hours of application. At -15°C for BA#3 and 0°C for Capbond, the tack and hard times, as expected, increased significantly (Table 3). These results indicate the need for similar nominal protection of these materials when they are used at cold temperatures.

The most significant finding of the cold temperature tack and hard time tests, however, was that it was necessary to maintain and mix components A and B of Capbond at 22°C before application at 0°C. Mixing this material at 22°C, and allowing the reaction to initiate (ie, thermal-setting), helps to ensure that the material will set at low temperatures. The Capbond material that was preconditioned to 0°C (and not thermal-set) prior to use had not hardened (when applied in a thin film) within 24 hours. Note, however, that thermal-setting is not required for BA#3. All components of BA#3 (resin and BPO) can be stored, mixed and placed at -15°C and will still tack, harden and develop sufficient strength within 24 hours.

3.2.2 Compressive Strength Results

The compressive strength results for all materials, at the applicable temperatures, are reported in Table 4.

At 22°C, there was no difference in the 1- and 7-day compressive strengths for either BA#3 or Capbond. This result indicates that the full strength of these materials is achieved after one day of curing at 22°C. Also at 22°C, the compressive strength of BA#3 is approximately three times as great as that of Capbond (ie, 113 vs 36 MPa). However, as will be discussed in Subsection 3.3, the breaking torque developed by BA#3

was not greater (but was less than) that of Capbond. Therefore, compressive strength alone is not a good indicator of the potential torque resistance that will be developed by each material.

Another important observation from monitoring compressive strength is that the cold curing temperatures of -15°C for BA#3 and 0°C for Capbond retarded the strength development of both materials. After 7 days of curing at these temperatures (and with only 30 minutes of exposure to 22°C prior to testing), the compressive strengths of BA#3 and Capbond were only 33% and 73% of their respective 22°C strengths. If, however, the test specimens were allowed 24 hours of exposure to 22°C (after 6 days of cold temperature curing), the compressive strengths of BA#3 and Capbond rose to 80% and 100% of their respective 22°C strengths. This result is significant because, if these materials must be used at cold temperatures, it indicates that additional strength will develop once the ambient temperature rises.

3.3 Anchor Bolt Tests

The results (ie, breaking and prevailing torques) of the anchor bolt tests are reported in Tables 5, 6, 7 and 8. In Tables 5 and 6 are the results of the room temperature tests for BA#1 and BA#2, respectively. Table 7 contains the results of tests for BA#3, which were conducted at 22° and -15°C , and similarly, Table 8 contains the results of tests for Capbond, which were conducted at 22° and 0°C . Unless noted, the breaking torque results are the average of two test results, whereas the reported prevailing torque is the minimum value of the two tests. In general, the prevailing torques were extremely variable and subject to interpretation, and a "single" value is reported only to indicate what may be expected. As such, the focus of this subsection will be on the breaking torque (ie, ultimate adhesive strength) results, and specific comments for each product are discussed as follows:

(i) VL T Bolt Adhesives #1 and #2 (BA#1 and BA#2)

Based on the relatively poor breaking torque results (Table 5) for BA#1, the anchor bolt tests at -15°C using this product were not conducted. For BA#2, improved breaking torques (Table 6) were obtained; however, use of this product was also discontinued due to its poor workability.

BA#1 contained 10% plasticizer (by mass) in an attempt to enhance the prevailing torque developed by this material. According to the manufacturer, incorporation of a plasticizer will result in a more flexible hardened product, which in turn will theoretically jam and clog between the threads of the anchor bolt and nut, as the nut is removed. However, what actually occurred is that, rather than jamming or clogging, this material was simply peeled away from the threads of the bolt by the turning nut. Further, not only did this material have a relatively poor prevailing torque, it appears as though the breaking torque (ie, adhesive strength) of BA#1 was impaired by the presence of the plasticizer. The plasticizer, being inert and non-reactive, likely inhibited the cross-linking of the polymer, thus reducing the shear and compressive strengths of BA#1. This result is clearly evident from the higher breaking torques that were obtained for BA#2. BA#2 was identical to BA#1, except that it did not contain any plasticizer. However, since BA#2 had poor workability, it was dropped from further testing. Due to the very high percentage of filler (75% by mass), this material was very difficult to work with, particularly at -15°C . Therefore, the ultimate outcome of these tests was the formulation of BA#3. Plasticizer was not used in BA#3 and its filler content was reduced to 50% (from 75% by mass) to improve its workability.

One final conclusion that emerged from these tests was that the adhesive strengths of both materials were independent of the initial level of pretorque and the diameter of the anchor bolt. For example, for BA#2, the unit breaking torque was calculated to be 0.259 and 0.288 N.m/mm² for the 28.5-mm (1-1/8 in.) diameter non-pretorqued and pretorqued anchor bolts, respectively. The corresponding value for the 38-mm (1-1/2 in.) diameter anchor bolts was 0.274 N.m/mm², regardless of the assembly having pretorque or not. [Note: To calculate the unit breaking torques, an effective contact area between the anchor bolt and nut was assumed to be the projected surface of the threads (ie, the outside diameter of the threads) x the height of the nut.]

(ii) VLT Bolt Adhesive #3 (BA#3)

The breaking torques for BA#3 (Table 7), at 22°C, were very comparable to those for BA#2. In terms of unit values, for the 28.5-mm (1-1/8 in.) diameter bolts, the breaking torques for the non-pretorqued and pretorqued assemblies were 0.238 and 0.288 N.m/mm², respectively. Corresponding values for the 38-mm (1-1/2 in.) diameter bolts were 0.264 and 0.242 N.m/mm² for the non-pretorqued and pretorqued assemblies, respectively. Here again, the results indicate the essential independence of adhesive strength on the initial level of pretorque and diameter of the anchor bolt.

One of the most significant findings from these tests, however, was that improved adhesive strengths were obtained when BA#3 was mixed, placed and cured at -15°C. On average, the unit breaking torques increased by at least 75% over the 22°C results. For the 28.5-mm (1-1/8 in.) diameter bolts, the unit breaking torques for the non-pretorqued and pretorqued assemblies were 0.485 and 0.400 N.m/mm² (vs. 0.238 and 0.288 N.m/mm² at 22°C), respectively. A corresponding value for the 38-mm (1-1/2 in.) non-pretorqued anchor bolt was 0.460 N.m/mm² (vs. 0.264 N.m/mm² at 22°C). The two 38-mm (1-1/2 in.) diameter pretorqued bolts did not fail. The reason for the improved strength at -15°C may be due to a slowing down of the polymerization reaction. Fewer polymer chains would have been initiated at this temperature, at one time, leading to longer individual chains, and hence a relatively more flexible and tougher hardened product. Also, BA#3 was very runny at 22°C, and there was a danger of segregation of the filler (silica flour) and the vinyl ester resin. This segregation did not occur at -15°C.

Another important finding was that there were three 38-mm (1-1/2 in.) diameter bolts (ie, one non-pretorqued and two pretorqued) prepared at -15°C that did not fail after an application of 2375 N.m (1750 ft.lb) torque (Table 7). These bolts were then heated in an oven to 100°C for approximately 2-1/2 hours and then tested (ie, untorqued) while still hot. The result was that these bolts failed at an average torque value of 1460 N.m (1075 ft.lb). The importance of this result was that, while the breaking strength of BA#3 reduced by at least 35% due to this severe exposure, it also indicated a method by which nuts might be removed and reused, if necessary.

(iii) Capbond HS - Rapid (Capbond)

The best breaking torques whether this material was applied and cured at 22°C or 0°C, were obtained with Capbond (Table 8). At 22°C, the unit breaking torques for the 28.5-mm (1-1/8 in.) diameter non-pretorqued and pretorqued bolts were 0.441 and 0.476 N.m/mm², respectively. Corresponding values for the 38-mm (1-1/2 in.) diameter non-pretorqued and pretorqued bolts were 0.467 N.m/mm² and 0.505 N.m/mm², respectively. At 0°C, the unit breaking torques for the 28.5-mm (1-1/8 in.) diameter non-pretorqued and pretorqued bolts were 0.503 and 0.608 N.m/mm², respectively. A

corresponding value for the 38-mm (1-1/2 in.) diameter non-pretorqued bolts was 0.505 N.m/mm², while the pretorqued bolts did not fail at an applied load of 0.530 N.m/mm². From these results, and very similar to BA#3 (and the other products), the independence of adhesive strength and the diameter of the anchor bolt is evident. However, the independence between the adhesive strength and initial level of pretorque is not as clear. In all these tests, the pretorqued bolts had breaking torques greater (between 5% and 20%) than those of their corresponding non-pretorqued bolts. It was also noted that similar to BA#3 the adhesive strengths were higher, by approximately 15%, when Capbond was applied and cured at a colder temperature (0°C).

The 38-mm (1-1/2 in.) diameter anchor bolts that did not fail (ie, one non-pretorqued and two pretorqued), after an application of 2415 N.m (1700 ft.lb), were heated for 3 hours at 100°C and subsequently tested hot. These bolts then failed at an average torque of 480 N.m (355 ft.lb). Clearly, the epoxy-based material is more adversely affected (than BA#3) by the exposure to an elevated temperature.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations arising from this test program are summarized as follows:

- (i) The following organic materials are recommended for use in securing transmission tower anchor bolts, so as to prevent or limit unauthorized persons from removing them.

- at an ambient temperature of between 30° and 0°C, an epoxy-based product, Capbond HS - Rapid (Capbond)

- at subfreezing temperatures (down to a minimum of -15°C), a vinyl ester-based product, VL Bolt Adhesive #3 (BA#3)

Average¹ breaking torques in excess of 1100 N.m (810 ft.lb) and 2100 N.m (1550 ft.lb) were obtained when Capbond was applied at 22°C to the 28.5-mm (1-1/8 in.) and 38-mm (1-1/2 in.) diameter bolts, respectively. Equivalent (and sometimes better) results were obtained when Capbond was applied at 0°C. At -15°C, the corresponding average values for BA#3 were 1000 N.m (730 ft.lb) and 2050 N.m (1510 ft.lb) for the 28.5-mm (1-1/8 in.) and 38-mm (1-1/2 in.) diameter bolts, respectively. Note that BA#3 can also be used at above freezing temperatures; however, the breaking torques at 22°C were only approximately 60% of those obtained at -15°C. Increased torque resistance for BA#3 at 22°C can probably be obtained by reducing the amount of catalyst (BPO).

- (ii) These materials are recommended for use where the material can be applied to both threaded surfaces (ie, around the perimeter of the bolt and on the inside of the nut).

1. Average results include the results from the non-pretorqued and pretorqued anchor bolt tests, as there appeared to be an essential independence of breaking torque and the initial level of pretorque. See further discussion in "Conclusions and Recommendations (iii)".

- (iii) For BA#3, the unit breaking torques were independent of the diameter of the anchor bolt, as well as the level of initial pretorque of the nut. For Capbond, the same independence of unit breaking torque and anchor bolt diameter was observed; however, there appeared to be a strength gain of between 5% and 20% when the nut was pretorqued.
- (iv) Nominal protection consisting of covering the anchor bolt with a plastic sheet is recommended when using both materials. This precaution is especially important if inclement weather (eg, rain or snow) is forecast within approximately two hours of use.
- (v) When using Capbond at low ambient temperatures (eg, 0⁰ to 10⁰C), the material must be thermal-set. This means that both components must be at a temperature of approximately 22⁰C when they are mixed and before using it in colder (eg, 0⁰C) ambient conditions. BA#3 does not have to be thermal-set. At temperatures as low as -15⁰C, the materials (ie, resin and BPO) can be stored, mixed, placed and cured at this temperature.
- (vi) Practical periods of use for Capbond and BA#3 at 22⁰C were approximately 8 and 15 minutes, respectively. At 0⁰C for Capbond and -15⁰C for BA#3, these working times, based upon the gel time results, are expected to increase. Improved (ie, longer) working times at 22⁰C for both products may be obtained when smaller quantities of each material are mixed during actual field use. Note that in these tests, approximately 1000 mL of material were mixed to secure only 8 anchor bolts at a time (see further discussion in Section 5.0).
- (vii) The breaking torques, of both products, were adversely affected by prolonged (2-1/2 to 3 hours) exposure to 100⁰C and when tested (ie, untorqued) hot. Capbond's torque was reduced by approximately 80% and BA#3 lost approximately 35% of its peak resistance under these conditions. This result indicates a method by which the nuts may be removed and reused, if necessary.

5.0 FUTURE WORK

The next steps in the complete evaluation of Capbond HS - Rapid and VLT Bolt Adhesive #3 are briefly described below. These two work packages have been discussed with, and approved by, members of the Transmission Lines Design Department.

(a) Field Trial

These two products will be further evaluated by assessing their performance under field conditions. The products will be applied by a field crew (after appropriate instruction by the Civil Research personnel) to various anchor bolts on selected transmission towers. Towers located at the Ontario Hydro's Kipling Complex have been tentatively identified as being suitable for this work.

The objectives of this program are as follows:

- (i) Comments and observations made by the field personnel regarding the handling and use of these materials will be used in finalizing the recommended installation procedures.

- (ii) Currently, arrangements are being made with the manufacturer of these products to supply the materials in smaller "injection kits". This will make it easy to use these materials in the field and reduce wastage. The use of these "injection kits" must be tested under field conditions.
- (iii) Based upon the results of items (i) and (ii) above, a standard Ontario Hydro specification covering the handling and use of these materials will be prepared.
- (iv) The anchor bolt nuts which are secured during the field trials will be tested (ie, untorqued) at scheduled dates in the future. These data will provide information on the long-term durability of these products under real environmental conditions.

(b) **Long-term Strength and Durability Under Accelerated Aging Conditions**

One key result of the present study is the strength regression of these materials when subjected to elevated temperatures, and as such, it indicates a means of "accelerating" any potential long-term degradation. Therefore, a program will be initiated where anchor bolt assemblies, similar to those tested in this study, will be subjected to an elevated temperature (eg, 50°C) for various durations of time. The results of this program will be used to assess the long-term stability of these materials.

In addition to the above-mentioned programs, another solution being pursued is to encase the anchor bolt assembly in a suitable rapid-setting organic material, thereby preventing or limiting unauthorized access.

Approved by:



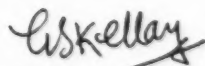
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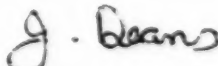


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1. Deans, J.J., "Evaluation of Organic Materials for Securing Anchor Bolt Assemblies Used for Tower Lines," Ontario Hydro Research Division Report S89-38-K, September 27, 1989.

TABLE 1
PRODUCTS TESTED

Product Name	Resin Type	% Plasticizer (by mass)	% Filler (by mass)	Mix Proportions (by mass)			
				% BPO		A:B	
				22°C	-15°C	22°C	0°C
VL T Bolt Adhesive #1	Modified Vinyl Ester	10	75	2	3	--	--
VL T Bolt Adhesive #2	Modified Vinyl Ester	0	75	2	3	--	--
VL T Bolt Adhesive #3	Modified Vinyl Ester	0	50	2	3	--	--
Capbond HS-Rapid	Epoxy	0	0	--	--	71:29	71:29

NOTES:

- (1) BPO = Benzoyl Peroxide
(2) A:B = Component A : Component B

TABLE 2
ANCHOR BOLT TESTS

Product	Anchor Bolt Dia. (mm)	Number of Specimens					
		22°C		0°C		-15°C	
		No Pre-Torque	Pre-torque	No Pre-Torque	Pre-torque	No Pre-Torque	Pre-torque
VLT Bolt Adhesive #1	28.5	2	2	--	--	2	2
	38	2	2	--	--	2	2
VLT Bolt Adhesive #2	28.5	2	2	--	--	2	2
	38	2	2	--	--	2	2
VLT Bolt Adhesive #3	28.5	2	2	--	--	2	2
	38	2	2	--	--	2	2
Capbond HS-Rapid	28.5	2	2	2	2	--	--
	38	2	2	2	2	--	--

NOTES:

- (1) 28.5 mm diameter = 1-1/8 in. diameter.
38 mm diameter = 1-1/2 in. diameter.
- (2) Pretorque of 270 N.m. (200 ft.lb) for the 28.5 mm diameter bolts.
Pretorque of 410 N.m. (300 ft.lb) for the 38 mm diameter bolts.
- (3) For tests at 22°C, materials were cured at that temperature for 7 days.
For tests at 0° or -15°C, materials were cured for 6 days at 0° or -15°C followed by 24 hours at 22°C.
- (4) All materials were applied, cured and tested with the anchor bolt in the vertical position.

TABLE 3
GEL, TACK AND HARD TIMES

Product	Gel			Tack			Hard		
	22°	0°	-15°	22°	0°	-15°	22°	0°	-15°
VLT Bolt Adhesive #1	20	--	280	15	--	45	DNT	--	DNT
VLT Bolt Adhesive #2	17	--	90	8	--	15	30	--	180
VLT Bolt Adhesive #3	25	--	230	12	--	45	30	--	300
Capbond HS-Rapid	5	23	--	80	210	--	240	1080	--

NOTES:

- (1) Gel, tack and hard times are in minutes.
- (2) Gel times are for a 100 mL sample.
- (3) Tack and hard times were obtained for a 0.5 mm thick film of each material using a Dry Time Recorder.
- (4) Temperature in degrees celsius.
- (5) For the 22°C tests (VLT Bolt Adhesives #1, #2, #3 and Capbond HS-Rapid) and the -15°C tests (VLT Bolt Adhesives #1, #2, #3), the materials were stored and mixed at those temperatures.
- (6) For the 0°C tests (Capbond HS-Rapid), the materials (ie, components A and B) were stored and mixed at 22°C.
- (7) DNT = did not harden (material had set, however).

TABLE 4
COMPRESSIVE STRENGTH¹

Product	Curing Temperature ²									
	22°C		0°C followed by ³ 24 h at 22°C		0°C followed by ⁴ 30 min at 22°C		-15°C followed by ³ 24 h at 22°C		-15°C followed by ⁴ 30 min at 22°C	
	1 Day	7 Day	1 Day	7 Day	1 Day	7 Day	1 Day	7 Day	1 Day	7 Day
VLT Bolt Adhesive #1	27.2	29.1	--	--	--	--	19.1 ⁵	19.1	11.1	20.2
VLT Bolt Adhesive #2	104.2	104.7	--	--	--	--	92.9 ⁵	92.4	40.7	51.8
VLT Bolt Adhesive #3	112.8	114.1	--	--	--	--	90.8	88.8	24.6	38.1
Capbond HS-Rapid	37.9	36.3	24.3	39.9	20.6	26.8	--	--	--	--

1 Compressive strength determined according to ASTM C 109.
All tests conducted at 22°C. Results in MPa.

2 For the specimens cured at 22°C (VLT Bolt Adhesives #1, #2, #3 and Capbond HS-Rapid), the materials were stored and mixed at 22°C.

For the specimens cured at -15°C (VLT Bolt Adhesives #1, #2, #3), the materials were stored and mixed at -15°C.

For the specimens cured at 0°C (Capbond HS-Rapid), the materials (ie, components A and B) were stored and mixed at 22°C.

3 Cured for 1 and 6 days at 0° or -15°C followed by 24 hours at 22°C.

4 Cured for 1 and 7 days at 0° or -15°C followed by 30 minutes at 22°C.

5 Compressive strength calculated from only one test specimen (ie, strength is usually based on the average of three specimens).

TABLE 5
TORQUE TEST RESULTS FOR
VLT BOLT ADHESIVE #1 AT 22°C

	Anchor Bolt Diameter (mm)			
	28.5		38	
	No Pre-Torque	Pre-Torque	No Pre-Torque	Pre-Torque
Breaking Torque	585 (432)	545 (402)	650 (480)	705 (520)
Prevailing Torque	385 (285)	425 (315)	450 (330)	290 (215)

TABLE 6
TORQUE TEST RESULTS FOR
VLT BOLT ADHESIVE #2 AT 22°C

	Anchor Bolt Diameter (mm)			
	28.5		38	
	No Pre-Torque	Pre-Torque	No Pre-Torque	Pre-Torque
Breaking Torque	665 (492)	740 (545)	1250 (925)	1250 (925)
Prevailing Torque	635 (470)	665 (490)	535 (395)	710 (525)

NOTES: (for Tables 5 and 6)

- (1) Breaking and prevailing torque reported in N.m. (Values in brackets are ft.lb).
Breaking torque is the average of two tests.
Prevailing torque is the minimum result of two tests (see note 6 below).
- (2) 28.5 mm diameter = 1-1/8 in. diameter
38 mm diameter = 1-1/2 in. diameter
- (3) Pretorque of 270 N.m (200 ft. lb) for the 28.5 mm diameter bolts.
Pretorque of 410 N.m (300 ft. lb) for the 38 mm diameter bolts.
- (4) All materials applied and cured for 7 days at 22°C.
- (5) Curing and testing conducted with the anchor bolt in the vertical position.
- (6) The prevailing torques were variable and subject to interpretation.
A single value is reported to be indicative of typical prevailing resistance that may be expected to be available once the bond is broken.

TABLE 7

**TORQUE TEST RESULTS FOR VLT
BOLT ADHESIVE #3 AT 22° AND -15°C**

	22°C				-15°C			
	28.5 mm ϕ		38 mm ϕ		28.5 mm ϕ		38 mm ϕ	
	No Pre-Torque	Pre-Torque	No Pre-Torque	Pre-Torque	No Pre-Torque	Pre-Torque	No Pre-Torque	Pre-Torque
Breaking Torque	610 (450)	740 (545)	1205 (890)	1105 (815)	1240 (915)	1025 (755)	2090 ² (1540)	>2375 ¹ (>1750)
Prevailing Torque	535 (395)	445 (330)	950 (700)	665 (490)	1315 (970)	1100 (810)	1545 ² (1140)	--

- ¹ None of the two anchor bolts failed after two applications of 2375 N.m (1750 ft.lb) torque. After heating these samples to 100°C for 2-1/2 hours and testing them hot, the breaking and prevailing torques were 1430 and 915 N.m (1055 and 675 ft.lb), respectively.
- ² The reported breaking and prevailing torques of 2090 and 1545 N.m (1540 and 1140 ft.lb) were the results from only one anchor bolt. This anchor bolt failed after approximately two minutes of being held at 2090 N.m (1540 ft.lb) torque.

The second sample did not fail after being held for five minutes at 2375 N.m (1750 ft.lb). After heating this sample to 100°C for 2-1/2 hours and testing it hot, the breaking and prevailing torques were 1485 and 915 N.m (1095 and 675 ft.lb), respectively.

NOTES:

- (1) Breaking and prevailing torque reported in N.m. (Values in brackets are ft.lb.)
Breaking torque is the average of two tests (unless otherwise noted above).
Prevailing torque is the minimum result of two tests (unless otherwise noted above; see also note 6 below).
- (2) 28.5 mm diameter = 1-1/8 in. diameter
38 mm diameter = 1-1/2 in. diameter
- (3) Pretorque of 270 N.m (200 ft. lb) for the 28.5 mm diameter bolts.
Pretorque of 410 N.m (300 ft. lb) for the 38 mm diameter bolts.
- (4) For the 22°C tests, material applied at 22°C and cured at that temperature for 7 days.
For the -15°C tests, material applied at -15°C, cured for 6 days at -15°C followed by 24 hours at 22°C.
- (5) Curing and testing conducted with the anchor bolt in the vertical position.
- (6) The prevailing torques were variable and subject to interpretation.
A single value is reported to be indicative of typical prevailing resistances that may be expected to be available once the bond is broken.

TABLE 8
TORQUE TEST RESULTS FOR
CAPBOND HS-RAPID AT 22° AND 0°C

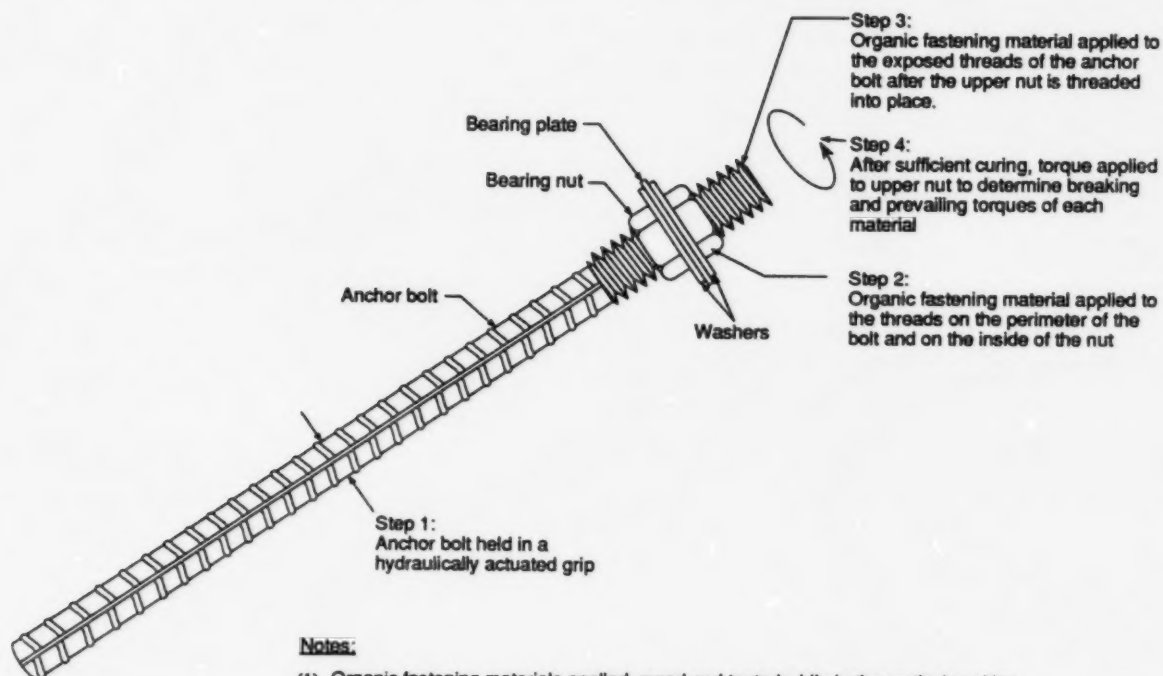
	22°C				0°C			
	28.5 mm ϕ		38 mm ϕ		28.5 mm ϕ		38 mm ϕ	
	No Pre-Torque	Pre-Torque	No Pre-Torque	Pre-Torque	No Pre-Torque	Pre-Torque	No Pre-Torque	Pre-Torque
Breaking Torque	1130 (835)	1220 (900)	2130 (1570)	2305 (1700)	1295 (955)	1560 (1150)	2305 ² (1700)	>2415 ¹ (1780)
Prevailing Torque	570 (420)	710 (525)	835 (615)	710 (525)	1045 (770)	995 (735)	995 ² (735)	--

- 1 None of the two anchor bolts failed after being held for five minutes at a torque of 2415 N.m (1780 ft.lb). After heating these samples to 100°C for 3 hours and testing them hot, the breaking and prevailing torques were 605 and 475 N.m (450 and 350 ft.lb), respectively.
- 2 The reported breaking and prevailing torques of 2305 and 995 N.m (1700 and 735 ft.lb) were the results from only one anchor bolt.

The second sample did not fail after being held for five minutes at 2095 N.m (1545 ft.lb). After heating this sample to 100°C for 3 hours and testing it hot, the breaking and prevailing torques were 230 (170 ft.lb) and 0 N.m, respectively.

ADDITIONAL NOTES:

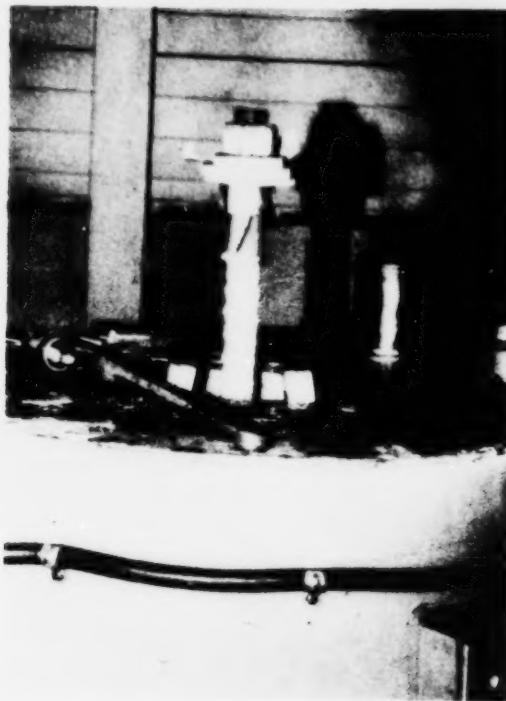
- (1) Breaking and prevailing torque reported in N.m. (Values in brackets are ft.lb.)
Breaking torque is the average of two tests (unless otherwise noted above).
Prevailing torque is the minimum result of two tests (unless otherwise noted above; see also note 6 below).
- (2) 28.5 mm diameter = 1-1/8 in. diameter
38 mm diameter = 1-1/2 in. diameter
- (3) Pretorque of 270 N.m (200 ft. lb) for the 28.5 mm diameter bolts.
Pretorque of 410 N.m (300 ft. lb) for the 38 mm diameter bolts.
- (4) For the 22°C tests, material applied at 22°C and cured at that temperature for 7 days.
For the 0°C tests, material applied at 0°C, cured for 6 days at 0°C followed by 24 hours at 22°C.
- (5) Curing and testing conducted with the anchor bolt in the vertical position.
- (6) The prevailing torques were variable and subject to interpretation.
A single value is reported to be indicative of typical prevailing resistance that may be expected to be available once the bond is broken.



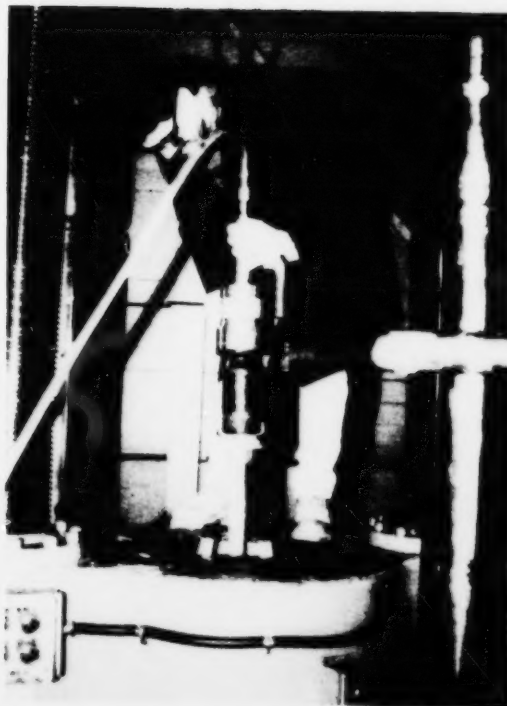
Notes:

- (1) Organic fastening materials applied, cured and tested while in the vertical position.
- (2) Breaking torque is the torque necessary to break the bond between the nut and anchor bolt (ie, torque required to initially move the nut).
- (3) Prevailing torque is the torque required to continue turning the nut after the initial bond is broken.

FIGURE 1
SCHEMATIC OF A TYPICAL ANCHOR BOLT TEST
(NTS)



(a) Anchor bolt held in a hydraulic grip



(b) Anchor bolt test being conducted with a pneumatic torque-multiplying tool

FIGURE 2